CH2M-36385-FP
Revision 0

Safety Analysis of the Demonstration Bulk Vitrification System

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-99RL14047

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Abstract

The U.S. Department of Energy (DOE) and CH2M HILL, Hanford Group, Inc. (CH2M HILL) [also referred to as the Tank Farm Contractor (TFC)] are evaluating the Demonstration Bulk Vitrification System (DBVS) as a supplemental treatment technology for low-activity waste (LAW) at the Hanford Site. As a new facility at Hanford, the safety analysis for the DBVS is being subjected to new and evolving DOE requirements.

Hazard categorization for the facility is being closely examined since this determines whether performance category (PC)-2 or PC-3 requirements are to be applied for natural phenomena hazards, as well as differing requirements under Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2004-2, *Active Confinement Systems*[1]. Questions have also arisen regarding application of DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*[2], or DOE-STD-1189-2008, *Integration of Safety into the Design Process*[3], format and content, as well as full implementation of DOE-STD-1186-2004, *Specific Administrative Controls*[4] and naming conventions and content requirements for the interim safety analysis documents under DOE O 413.3A, *Program and Project Management for the Acquisition of Capital Assets*[5] (e.g., Preliminary Documented Safety Analysis or Preliminary Safety Design Report). Another challenge is the integration of the programmatic chapters of the safety document with those of the Hanford tank farms, since the tank farms Safety Management Programs (SMP) are relied upon for the DBVS facility.

All of these issues and their resolutions, as well as the level of scrutiny to which internal and external regulators have held this project's safety analysis, will be discussed in this paper.

Introduction

The DBVS will receive waste from the single-shell tank (SST) 241-S-109 Partial Waste Retrieval System (PWRS) and treat the waste by converting it into containers of immobilized glass that meet the waste acceptance criteria for disposal at the Integrated Disposal Facility (IDF) on the Hanford Site. The DBVS is a full-scale research and development facility intended to demonstrate the effectiveness of the bulk vitrification process as a method for treatment and immobilizing LAW fractions from tank waste for onsite disposal. The purpose of the DBVS is to provide:

- Demonstration of the technology that can produce an acceptable immobilized waste product to support a decision to supplement current and planned tank waste immobilization technologies.
- An enhanced bulk vitrification testing program with the capability to test waste processing under full-scale radioactive conditions to provide design, construction, operating lessons learned, and operation training that could minimize technical and schedule risks for a full-scale bulk vitrification system.
- Demonstration of the safety and effectiveness of joule-heated melting for radioactive tank waste.
- Demonstration of melter throughput, availability, and reliability while processing an active waste stream.
- Demonstration that the waste form can meet the waste acceptance criteria for the Hanford IDF.
- Provide critical permitting data for the full-scale project.
- A forum to optimize technology, startup, and operation for a production facility.
- A forum for facility startup, operations and maintenance procedure development, and evaluation.

Background

The Supplemental Treatment Test and Demonstration Project is a research and development project with the goal of proving the suitability of bulk vitrification for treating LAW from tank farms for final disposal. In 2002, the DOE and CH2M HILL evaluated three supplemental treatment technologies for LAW:

- Cast stone
- Bulk vitrification
- Steam reforming.

Bulk vitrification was tentatively selected as the most promising of the three technologies at the Hanford Site and CH2M HILL was asked to perform additional full-scale tests with actual tank waste to fully evaluate bulk vitrification. The DBVS project is permitted by the Washington State Department of Ecology (Ecology) under a research development and demonstration permit issued in December 2007 (*Final Dangerous and/or Mixed Waste Research, Development, and Demonstration (RD&D) Permit for the Demonstration Bulk Vitrification Facility, Rev. 1, Permit No: WA 7890008967*[6]). Retrieval of tank SST 241-S-109 waste is authorized by Ecology's February 2005 approval of RPP-18812, *Tank S-109 Partial Waste Retrieval Functions and Requirements*[7].

The Supplemental Treatment Test and Demonstration Project has two components. One component is the DBVS, which will produce large containers of vitrified waste from SST 241-S-109. The other component is the SST 241-S-109 PWRS, which will retrieve waste from SST 241-S-109 and send the waste to the DBVS. The description of the SST 241-S-109 PWRS process systems is discussed in RPP-13033, *Tank Farms Documented Safety Analysis*[8] (Tank Farms DSA), and the controls associated with this phase of the waste retrieval and delivery to the DBVS are included within HNF-SD-WM-TSR-006, *Tank Farms Technical Safety Requirements*[9].

The immediate project benefit is demonstration of a treatment method which could immobilize significant amounts of waste contaminated with mobile, long-lived radionuclides in a timely fashion to reduce risk to the public and the environment.

The general waste form qualification objectives for operation of the DBVS are threefold.

1. Ensure that the waste packages produced in the operations of the research, development, and demonstration facility will meet long-term performance criteria and can be disposed at the Hanford IDF as treated LAW.

2. Ensure that the necessary data are collected at the required intervals to support future milestone decisions and future performance assessments.

3. Supply sufficient data to ensure that a production product control strategy can be implemented that is practical for the several thousand waste packages that might be produced in the follow-on production facility while supplying the necessary controls to ensure waste form quality.

Operations will be conducted as campaigns. A campaign plan will be prepared for each campaign that defines the type, quantity, and sequence of data acquisition such that Objectives 2 and 3 are satisfied (DOE/ORP-2003-23, *Research, Development, and Demonstration Permit Application for a Bulk Vitrification Test and Demonstration Facility*, Section 5.2[10]).

Details of the process parameters used for operation during these campaigns will be described in campaign plans and process memos. Table 1 provides a summary of currently planned full-scale campaigns in the DBVS, indicating the general purpose and estimating the number of glass containers expected to be produced by each test group.

Table 1. Summary of Currently Planned Full-Scale Tests in the Demonstration Bulk Vitrification System.

Group name	Group number	Estimated number of glass containers	Purpose
Full-Scale Simulant Demonstrations	40	5	Verify that the results obtained in engineering scale tests can be scaled to a full-size system using waste simulant. Includes rhenium spikes to help determine the amount of volatilization that occurs at full-scale relative to engineering scale tests.
Full-Scale Hot Demonstration	41	1	Verify that SST 241-S-109 waste can be processed in a full-size system using a fraction of actual waste combined with chemical simulant to mimic the baseline sodium loading. Begins validation of simulant test and supports determining the fate of technetium in a full-scale unit.
Full-Scale Hot Ramp-Up	42	5	Evaluate the effect of varying the quantity of SST 241-S-109 waste used in the waste feed on waste form quality. Completed when the waste feed is comprised of 100% SST 241-S-109 waste and the baseline operating conditions have been established. Also supports development of waste form qualification strategies.
Full-Scale Hot Baseline Establishment	43	5	Establish the variability of glass produced while operating at constant (baseline) operating conditions. Also supports development of waste form qualification strategies.
Full-Scale Hot Process Operational Window	44	15	Verify the size of a process operating window that will produce an acceptable waste package. While minimizing the waste feed variability, glassformer, waste package configuration, and process variables are varied to determine the effects on the final waste form. Tests will also verify that procedures to deal with interrupted melts work as expected and support development of waste form qualification strategies.
Full-Scale Hot Feed Envelope Verification	45	10	Verify that the process can treat other portions of the waste feed envelope by adjusting the SST 241-S-109 waste chemical composition with simulants. Glassformer and process conditions may be varied, as necessary. Also supports development of waste form qualification strategies.
Full-Scale Hot Process Improvement	46	10	Verify that optimized glass formulations produce acceptable waste forms when processed at full scale with actual waste. Supports development of waste form qualification strategies.

Notes:

Based on test purpose descriptions in PNNL-15048, *Waste-Form Qualification Compliance Strategy for Bulk Vitrification*, Pacific Northwest National Laboratory, Richland, Washington.

SST = single-shell tank.

Facility Overview

This section provides a brief overview of DBVS configuration and the processes performed to accomplish vitrification of tank waste.

The DBVS receives waste from SST 241-S-109, which is located in the 200 West Area of the Hanford Site. After receipt, DBVS mixes the waste with glass-forming minerals, dries the mixture, and uses a process referred to as In-Container Vitrification (ICV)[a] to vitrify the radioactive waste. A simplified diagram of the DBVS process is shown in Figure 1.

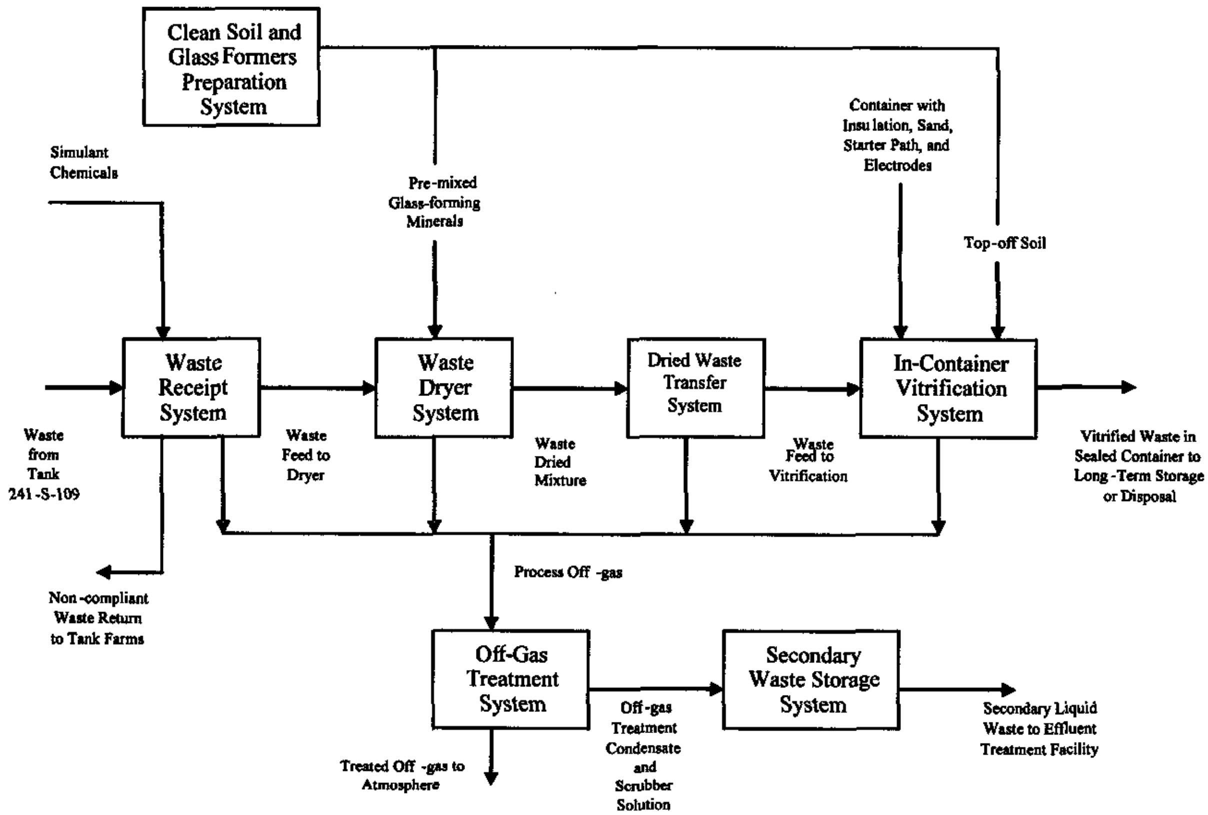


Figure 1. Demonstration Bulk Vitrification System Process.

The main process systems of the DBVS are the following:

- Clean Soil and Glass Formers Preparation System
- Waste Receipt System
- Waste Dryer System
- Dried Waste Transfer System (DWTS)
- ICV System

[a] ICV (In-Container Vitrification) is a trademark of AMEC, Inc., London, England.

- Core Sampling System
- Off-Gas Treatment System (OGTS)
- Off-Gas Treatment System Emergency Bypass System (OGTS Bypass System)
- Secondary Waste Storage System
- Temporary Immobilized Low-Activity Waste (ILAW) Storage.

Overall Mission Objectives

The DBVS approximates one of the six parallel process lines for the follow-on production vitrification facility described in RPP-16215, *Production Bulk Vitrification System, Preliminary Engineering Report*[11]. The demonstration is intended to verify in-container, bottom-up melting of radioactive waste as a viable technology. The demonstration mission will last approximately 18 months and vitrify approximately 200,000 gal of SST 241-S-109 saltcake waste diluted to approximately 5 M sodium (600,000 gal diluted volume) producing up to 50 containers of product.

Facility Siting

The site location for the 200 West Area of the Hanford Site is shown in Figure 2. The DBVS location within the 200 West Area is shown in Figure 3. The site is located immediately west of the 241-S Tank Farm in the 200 West Area of the Hanford Site. The wastes planned for treatment are currently stored in SST 241-S-109, a 750,000-gal SST located in the 200 West Area.

The site is west of the existing 241-S Tank Farm fence, in an area that has already been disturbed and will support process and ancillary equipment for the DBVS. The proposed location allows close access to existing electrical and raw water utilities, telephone, and Hanford local area network services. Surface materials consist of soft sand and soil that are free from surface contamination. The site is sufficiently level to provide for equipment placement with minimum grading or excavation. Cooper Avenue, which runs north-south on the west side of the 241-S Tank Farm, provides ingress and egress for the area.

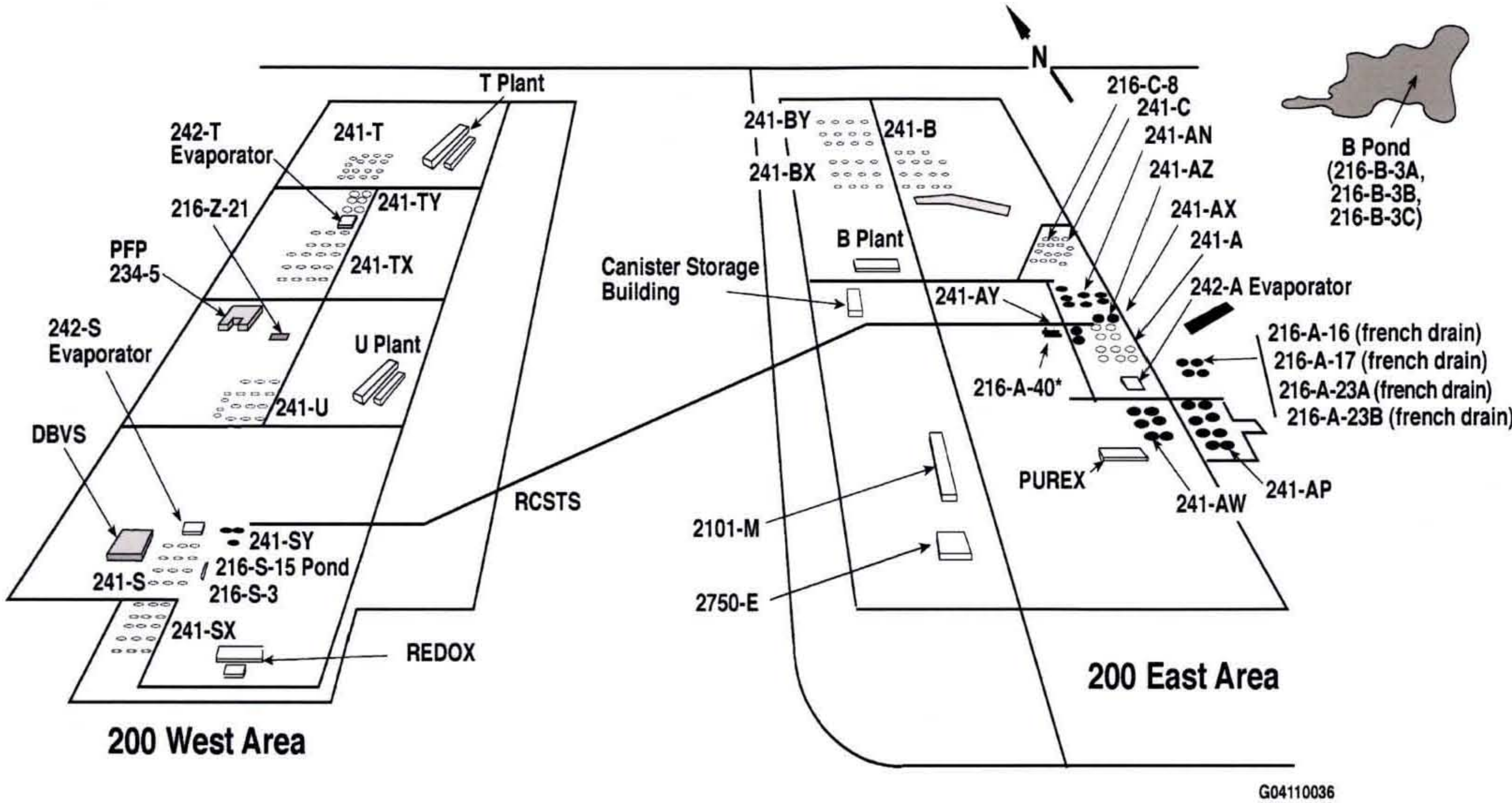
Facility Configuration

The DBVS facility consists of a number of process trailers, skids, enclosures, and staging areas. The major DBVS facility structures and their relative placement can be seen in Figures 4a and 4b.

200E	= 200 East Area.	LIGO	= Laser Interferometer Gravitational Wave Observatory.
200W	= 200 West Area.	NRDWL	= Nonradioactive dangerous waste landfill.
ENW	= Energy Northwest.	WTP	= Waste Treatment Plant.
ERDF	= Environmental Restoration Disposal Facility.		

Figure 2. Hanford Site.

Figure 3. Demonstration Bulk Vitrification System Location.



Underground waste tanks (designated by tank farms)

- ● double-shell tank
- ○ single-shell tank

DBVS = Demonstration Bulk Vitrification System (Facility).
PFP = Plutonium Finishing Plant.
PUREX = Plutonium Uranium Extraction (Facility).
REDOX = Reduction Oxidation (Plant).
* = Retention Basin
RCSTS = Replacement Cross-site Transfer System.

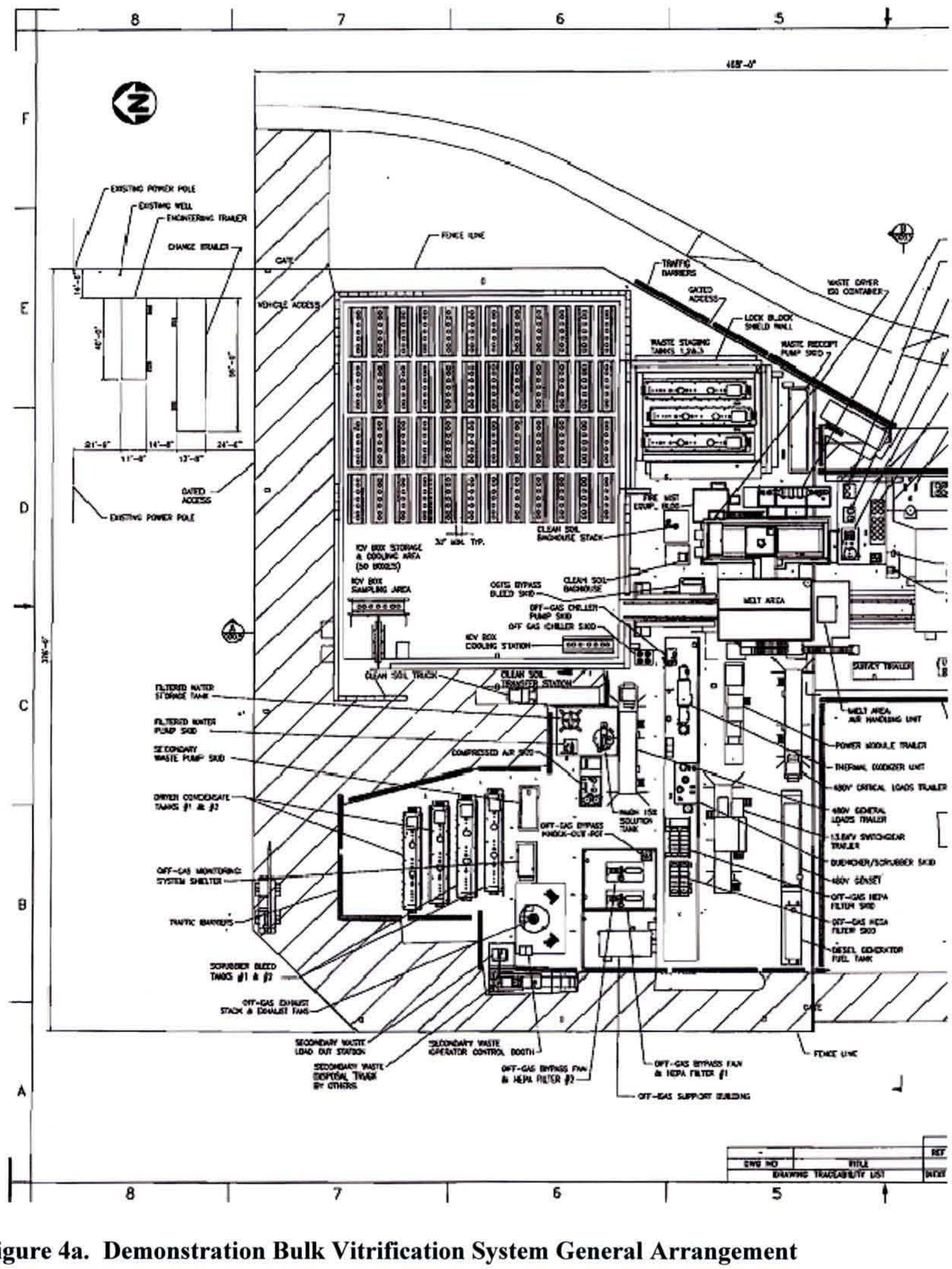


Figure 4a. Demonstration Bulk Vitrification System General Arrangement (Left Side of Sheet).

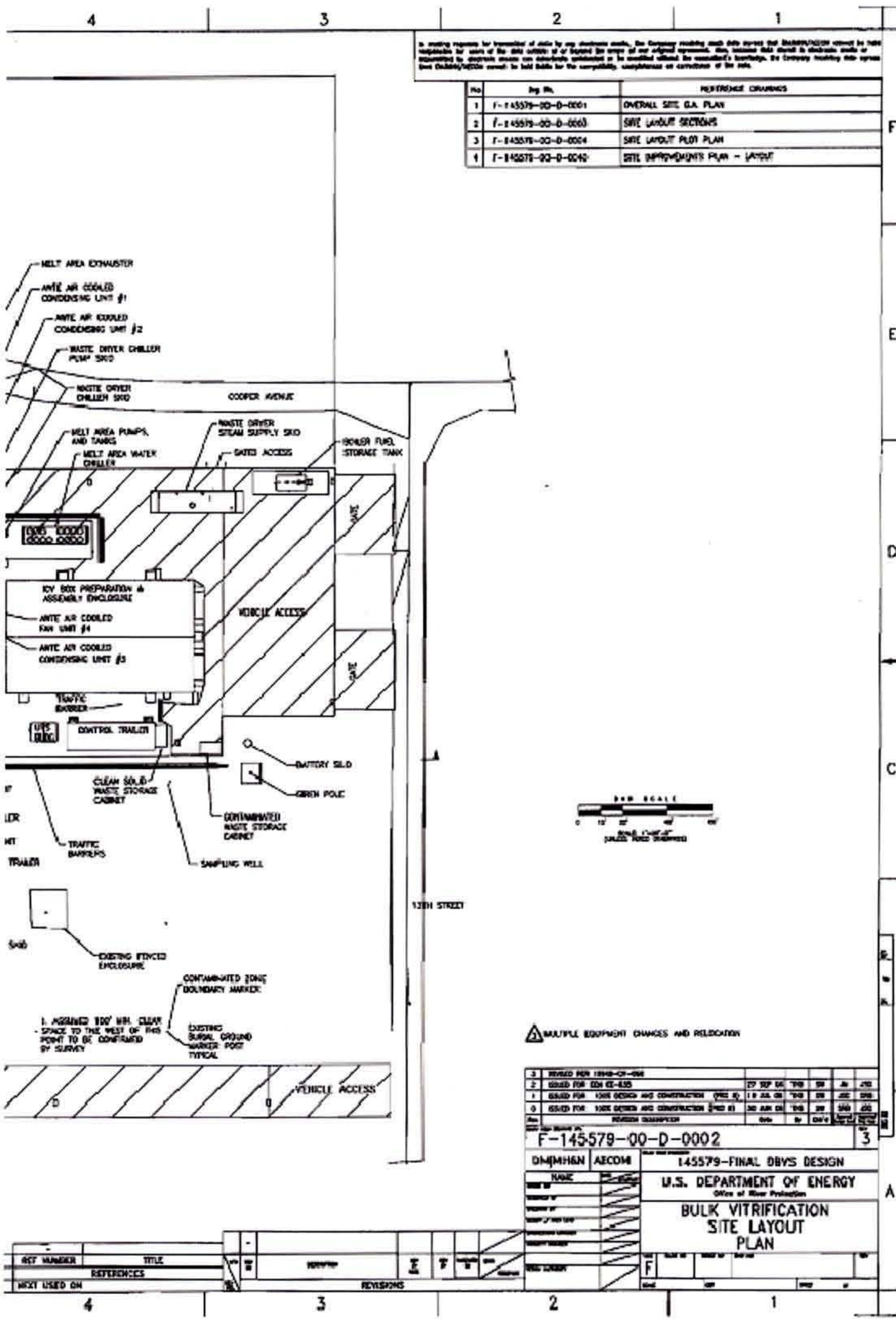


Figure 4b. Demonstration Bulk Vitrification System General Arrangement (Right Side of Sheet).

Demonstration Bulk Vitrification System Components

The DBVS consists of trailer-mounted and skid-mounted equipment suitable for field installation, operation, and removal at the completion of the project. The system includes the major components, systems, and areas listed below.

The general arrangement of the following components (see Figures 4a and 4b) includes:

- ICV Box Preparation and Assembly Enclosure Area
- Waste Receipt System
- Clean Soil and Glass Formers Handling System
- Waste Transfer Pump Skid and Liquid Waste Staging Tanks
- Waste Dryer System
- Waste Dryer Chilled Water and Steam Supply Systems
- DWTS
- ICV System
- OGTS
- OGTS Bypass System
- OGTS Stack and Stack Monitoring
- OGTS Treatment Chilled Water System
- OGTS Treatment Chemical Storage and Supply (caustic)
- Secondary Waste Storage System
- Temporary ILAW Storage.

Support Systems

Support systems are systems that are required to operate the DBVS, but are not directly involved with the process. The support systems consist of the following:

- Control trailer
- Personnel contamination control and survey station
- Backup generator
- Steam, compressed air, and filtered water systems
- Diesel generator fuel tanks.
- Power Module, Medium Voltage, 480 volts alternating current (Vac) Critical Loads
- 480 Vac General Loads trailers.

Safety Analyses

Pre-Conceptual and Conceptual Phases

With the commencement of pre-conceptual design in 2003, the first hazards analyses were conducted. A hazards and operability analysis (HAZOP) was completed in October 2003, which resulted in some design changes to the project (e.g., relocation of the waste dryer from an elevation directly over the ICV container to alongside). At that time, the project was primarily focused on proving the viability of the bulk vitrification technology rather than the method for drying and transporting the waste to the ICV. As a result, the DBVS was seen as more of a test than a project, and it was placed on a fast track for design, safety analysis, construction, and operation, rather than the "critical decision" process of DOE O 413.3[12], *Program and Project Management for the Acquisition of Capital Assets*. An overall schedule from early 2004 showed the project being built in 2005, operated through 2006, and the decontamination and decommissioning completed at the end of 2007.

At the 30% design point in April 2004, another HAZOP was conducted because the non-prototypic systems of the DBVS (including the waste receipt, waste drying, waste delivery, and OGTS) had developed to the point where the hazards could be determined more fully, and outside regulators had shown more interest in these systems than initially thought, forcing the project to shift its focus from a technology demonstration to a process demonstration. The original qualitative judgment from the safety analysts was that the project posed a low radiological risk (which would be borne out in later, quantitative analyses) and only a facility worker risk for toxicological exposures from toxic off-gases such as NOx (this judgment would be shown to be significantly understated during later analyses).

In the beginning, the hazards analyses for the project showed that there were five accident scenarios that would require control decision (others would be added later as the design matured):

- Flammable Gas
- Release of Toxic Off-Gases (e.g., NOx)
- Release of Dried Waste
- Waste Transfer Leak
- Aboveground Tank Failure.

The offsite consequences were considered to be bounded by similar accidents from the tank farms, so it was assumed that the equipment would be safety significant and not safety class.

Because of the initial premise of a technology rather than a process demonstration, and the original judgment as to the low collocated and offsite public risk, the regulators felt the design of the support systems to the ICV containers was less robust than necessary, and the systems' compliance with requirements of DOE O 420.1A, *Facility Safety*[13], was continually challenged throughout 2004 and into early 2005. The major point of contention was compliance with the "multiple barriers" requirements of the DOE order.

Revision 0 of the Preliminary Documented Safety Analysis

The first Preliminary Documented Safety Analysis (PDSA) (RPP-23429, *Demonstration Bulk Vitrification System Preliminary Documented Safety Analysis*, Revision 0[14]) for the project was submitted in January 2005, and approved by the U.S. Department of Energy, Office of River Protection (ORP) in March 2005. This PDSA was envisioned to eventually become an addendum to the Tank Farms DSA, so its accident analyses was written as a "delta" to analyses performed for tank farms, following the format of DOE-STD-3009-94 (i.e., differences in frequency and consequence to the suite of accidents analyzed for tank farms where possible, with unique DBVS accidents addressed separately). The hazard category for the project was divided, at that point, into two phases. During the first phase, the project was considered to be "less than Hazard Category 3" due to a very limited material at risk (MAR) of approximately 1,000 gal; and in the second phase, it was considered to be Hazard Category 2, due to its physical connection to tank farms (an inventory of the radiological constituents within DBVS was not performed).

Subsequent to the approval of the PDSA for the project, the following events occurred during the remainder of 2005 and 2006.

- A basic analysis assumption for toxic off-gas confinement upon a loss of active ventilation, in which a passive ventilation path at the ICV container inlet was to be established through an inlet stack (which would have no valving or other blockages), was found to be faulty. This was because of poor communications between the various engineering groups for the project (which were located in Trail and Vancouver, British Columbia, as well as in Richland, Washington). During the transition from active to passive ventilation, it was well understood that the ICV would experience a period of transition in which the pressure in the box would go slightly positive. What was not understood was that the design of the ICV lid seal was for negative pressure (i.e., restricting in-leakage), but not for positive pressure. As a result, this transition period would result in toxicological consequences at 100 meters above Temporary Emergency Exposure Limit (TEEL)-3 (i.e., high onsite toxicological consequences). This, combined with the recommendation from the Defense Nuclear Facilities Safety Board (DNFSB 2004-2) regarding active ventilation controls for confinement, developed into a safety-significant active ventilation system for the DBVS (emergency bypass ventilation system), even though the facility remained within Hazard Category 3.

- An external review determined that the hazards analysis process needed more facility worker focus, and so a Process Hazards and Operability Analysis (PrHOA) process was instituted via RPP-PLAN-26909, *Supplemental Treatment Test and Demonstration Facility Process Hazard and Operation Analysis Plan*[15]. This new hazards analysis process was used to review the DBVS design and planned operations from August through December 2005.

- The project received correspondence from its subcontractor in which projected cost estimates predicted over-runs and significant schedule delays. This was reported to ORP and ORP, in turn, directed compliance with a CH2M HILL recovery plan. In addition, the project was to be placed under the requirements of DOE O 413.3 and was directed to prepare and receive approval of critical decision packages per that order.

- An independent technical review panel was commissioned by CH2M HILL and ORP in January 2006, to recommend improvements to the vitrification process, specifically with the regard to the technetium mass balance. The ability to show that all of the technetium would be immobilized within the glass matrix had not been accomplished during engineering and full-scale testing to this point and was crucial to the environmental permitting for the project. The changes coming from this panel drove several process changes (e.g., cold cap management and glass-former material recipe changes), and ultimately would take through the summer of 2007 to finally resolve through several more full-scale melt tests at the Horn Rapids test site adjacent to the Hanford reservation. All of the process and design changes deriving from these test results needed to be reflected in updated safety analyses.

- In May 2006, as the design was nearing completion (the design was due for completion in July 2006, and the PDSA due for submittal in September), an expert review panel was commissioned by CH2M HILL to review the DBVS project. This panel had just completed a similar review on the Waste Treatment Plant being designed and constructed by Bechtel National, Inc., on the Hanford Site. This review was very thorough and lasted until September 2006. Several changes resulted from this review, but the evaluations and incorporation of these changes were not completed until after the design was complete on July 28, 2006, and were not reflected in the revision to the PDSA submitted for ORP review and approval on October 19, 2006.

Revision 1 of the Preliminary Documented Safety Analysis

The revision to the PDSA submitted to ORP in October 2006, was significantly changed from the previous revision submitted in 2005. The major changes included the following.

- The DBVS PDSA was no longer envisioned to be an addendum to the Tank Farms DSA. As a result, the hazard and accident analyses were performed again to derive the accidents directly from the hazards associated with the DBVS facility, rather than relying on a "delta" analysis from tank farms. The programmatic chapters of the PDSA continued to reference the Tank Farms DSA as the DBVS facility shared SMPs with the Tank Farm facility. The PDSA remained in the format of DOE-STD-3009-94, though there was some question at the time regarding whether the format should be shifted to follow DOE-STD-1189-2008. It was determined during discussions with ORP that the format should not be changed.

- Offsite radiological analyses were performed for the unique DBVS accident scenarios, which corroborated earlier assumptions that the offsite risk evaluation guideline was not challenged, and allocation of controls as safety significant rather than safety class was appropriate.

- Where chemical inventory exceeded the Threshold Quantities in 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals"[16], or 40 CFR 68, "Risk Management Plans"[17] (or 40 CFR 355, "Emergency Planning and Notification"[18], if not listed in 29 CFR 1910.119), a quantitative or qualitative analysis was performed to evaluate potential chemical exposures. The elements of Process Safety Management were implemented as applicable. (Revision 0 of the PDSA explained that no chemicals exceeded the threshold quantities of 29 CFR 1910.119.)

- Where chemical inventory exceeded the reportable quantities in 40 CFR 302, "Designation, Reportable Quantities, and Notification"[19] additional hazard analysis was required if significant chemical consequences to facility workers or collocated workers could be reasonably expected. The purpose of evaluating potential significant chemical consequences was threefold: (1) to identify preventive and mitigative controls that may be an opportunity for improvement of the final process design or operational procedures; (2) to evaluate the adequacy of the chemical management program and other SMPs to control the hazard; and (3) to apply the DOE-STD-3009-94 safety-significant structures, systems, and components (SSC) criteria. SSC designation or specific administrative controls (SAC) based on worker safety for non-Standard Industrial Hazard (SIH) chemical hazards were limited to those whose failure was estimated to result in prompt worker fatality, serious injuries to workers, or significant chemical exposures. SSCs and administrative controls (AC) were considered for elevation to safety SSC or SAC status for SIH involving quantities of industrial chemicals that had the potential for significant facility worker consequence. However, safety SSC designation or SACs for industrial chemical SIH were only appropriate if significant improvement in worker protection could be realized beyond what was provided through contractually mandated SMPs and compliance with national consensus codes and standards such as those established by the American Society of Mechanical Engineers.

- Where chemical inventory did not exceed the reportable quantities of 40 CFR 302, further hazard analysis was not necessary. The adequacy of hazard controls provided by SMPs or other implemented controls was confirmed.

  Examples of conditions where a significant consequence to the facility worker were considered for safety-significant SSCs or SACs included:

  - Energetic releases of high concentrations of radiological or toxic chemical materials where the facility worker would normally be immediately present and therefore unable to take self-protective actions

- Deflagrations or explosions within process equipment or confinement/containment structures or vessels where grievous injury or death to a facility worker may result from the fragmentation of the process equipment failing or the confinement (or containment) with the facility worker close by

- Chemical or thermal burns to a facility worker that could reasonably cover a significant portion of the facility worker's body where self-protective actions are not reasonably available due to the speed of the event or where there may be no reasonable warning to the facility worker of the hazardous condition

- Exposures to radiological or toxic materials of sufficient magnitude that death or ongoing large-scale medical intervention may reasonably be expected to result

- Leaks from process systems where asphyxiation of a facility worker normally present may result.

- The DBVS was evaluated to be a Hazard Category 3, based on radiological inventory and fissile material inventory, as outlined in the methodology of DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*[20].

- The source term assumptions were adjusted to be more consistent with the facility design (i.e., in-situ values for radiological and toxicological constituents used in the previous revision were replaced with more realistic values deriving from the diluted retrieval effluent from the waste tank in tank farms). This source term would be protected via technical safety requirement (TSR).

- The ICV container vacuum would be assured by a safety-significant OGTS bypass system.

- Additional safety-significant SSCs were designated (solely driven by facility worker protection from "significant" facility worker hazards).

- Whenever SMPs were relied upon for risk reduction, key elements of these programs would be identified during DSA development as SACs in accordance with DOE-STD-1186-2004.

Preliminary Safety Design Report (Revision 1-A of the Preliminary Documented Safety Analysis)

In July 2006, DOE O 413.3 was revised to DOE O 413.3A, which, among other changes, changed the nomenclature of the safety documentation for CD-1 and CD-2 to "Conceptual Safety Design Report (CSDR)" and "Preliminary Safety Design Report (PSDR)," respectively. The project had previously been directed to follow the requirements of the order, and had already received approvals for CD-0 and CD-1. The CD-2 package was scheduled for submittal to ORP and DOE-Headquarters during the summer of 2007, and discussions with ORP during the autumn of 2006 and the beginning of 2007 centered on the required format for the next revision of the PDSA for inclusion in the CD-2 package.

DOE O 413.3A referenced DOE-STD-1189-2008 as the source of information regarding the form and content of a PSDR. However, some of the DBVS design was completed to a degree beyond that required for a PSDR in DOE-STD-1189-2008 (i.e. remained unchanged from the PDSA submittal in October 2006) and other areas had been changed from the "final design" analyzed in that PDSA. ORP and CH2M HILL agreed that CH2M HILL would not completely revise the PDSA, but would supplement the PDSA with PSDR-level analyses on those areas of the design that had been modified subsequent to the previous design freeze date of July 2006.

The design changed substantially in the latter half of 2006 and the first half of 2007 for several reasons: (1) recommendations from the expert review panel; (2) results of a value engineering facilitated session conducted by CH2M HILL and ORP; and (3) reformulation of the glass-forming minerals and additives by the Pacific Northwest National Laboratory to address radionuclide mass balance issues first discussed in 2005. As a result of these inputs to the project, the following substantial changes were made to the design in 2007.

- The OGTS NOx reduction approach was modified from a tail-end catalytic reduction process to a head-end thermal process. The Ammonia Gas Supply System and selective catalytic reduction unit were eliminated. A propane-fired thermal oxidizer was added upstream of the gas scrubber and downstream of the sintered metal filters with an accompanying gas storage and supply system.

- The ICV feed material was modified by addition of cellulose fiber and glass-forming minerals to the glass-forming material supplied to the waste dryer. This change was made to eliminate the migration of molten ionic salts (a mechanism by which radionuclides were carried outside the glass matrix and thus not immobilized) through the ICV container refractory barrier.

- The DWTS was changed from a vacuum blower-driven pneumatic system to a mechanical auger system. Two vertical and two horizontal centerless augers replaced the pneumatic transport system. In addition, a feed hopper was installed under the waste dryer to supply the vertical augers.

- The design was also modified to fully enclose the Melt Area Enclosure structure, adding fans and filters to ventilate this structure.

- The size of the OGTS was reduced, mainly because of the replacement of the venturi scrubber (for acid gas removal) to a packed bed scrubber.

- The inclusion of the cellulose in the glass-former mixture added a new accident for analysis in this revision, Organic Nitrate Reactions.

- Incomplete information was available on several hazards at the time of the submittal of the PSDR, and these were identified as "items requiring further evaluation." These items included the following.

  - The inclusion of cellulose in the dried waste and glass-forming materials mixture could affect flammable gas generation in this mixture through increased thermolysis of the organic material. This required testing at the Pacific Northwest National Laboratory. Results showed that there was a significant increase in the generation of flammable gases, particularly in the waste dryer (time to 25% of the lower flammability limit dropped from well over 1 year to less than 1 day).

  - The inclusion of cellulose in the glass-forming materials presented a hazard of confined dust cloud explosions. Testing was performed at Fauske & Assoc., LLC to determine the combustibility of various percentages of dried waste and hydrogen content in the glass-former mixture. Results showed a large margin between the flowsheet values of dried waste (approximately 11 wt %) and combustibility limits.

  - The inclusion of cellulose in the dried waste and glass-forming materials mixture presented a hazard of entraining significant moisture in the feed material to the melt with subsequent steam generation. Engineering calculations showed that with approximately 25% moisture in the waste feed delivered to the ICV; the resultant steam formation could overwhelm the ventilation systems and cause a ground-level release of toxic off-gases. As a result, additional engineered and ACs were placed on the waste dryer and DWTS (e.g., a control to prevent the liquid waste inlet valves to the dryer and the dried waste discharge valve from being opened at the same time, and a process control on moisture content of the discharged dried waste).

  - The inclusion of cellulose in the dried waste and glass-forming materials mixture presented a hazard of exothermic organic-nitrate reactions in areas of the plant where this was undesirable (this exothermic reaction was desired in the ICV as a de-nitration reaction for control of the molten ionic salts). Particular areas where this reaction needed to be prevented were the waste dryer, waste hopper below the dryer, the DWTS, and the OGTS sintered metal filters. Data obtained from full-scale testing at the Horn Rapids Test Center showed that the organic levels in the carry-over material into the OGTS sintered metal filters was significantly reduced, reducing the hazard of exothermic reaction in this area, and the geometry of the DWTS (surface area to volume ratio) reduced the likelihood of a bulk temperature sufficient to induce the reaction in this area of the plant. However, analysis with Fauske & Assoc., LLC, showed that controls were required in the waste dryer and waste hopper. TSR controls were, therefore, placed on these areas to limit their temperatures below potential onset temperatures for the reaction.

On March 30, 2007, CH2M HILL submitted Revision 1-A of the PDSA (Revision 1 of the PDSA was still in review by ORP, but the design had continued to evolve after submittal due to internal and external recommendations). Revision 1-A included appendices with PSDR-level analyses on the "deltas" of the design, including sections on Fires and Explosions (resulting mainly from the inclusion of the propane thermal oxidizer), Dried Waste Releases (changes resulted from mechanical auger delivery system rather than a pneumatic transport), and an analysis of Organic Nitrate Reactions (the addition of the cellulose "fuel" for these reactions had elevated this accident scenario to one for which controls were now required).

Figure 5 provides a graphic representation of the parallel development of the project design and safety analysis.

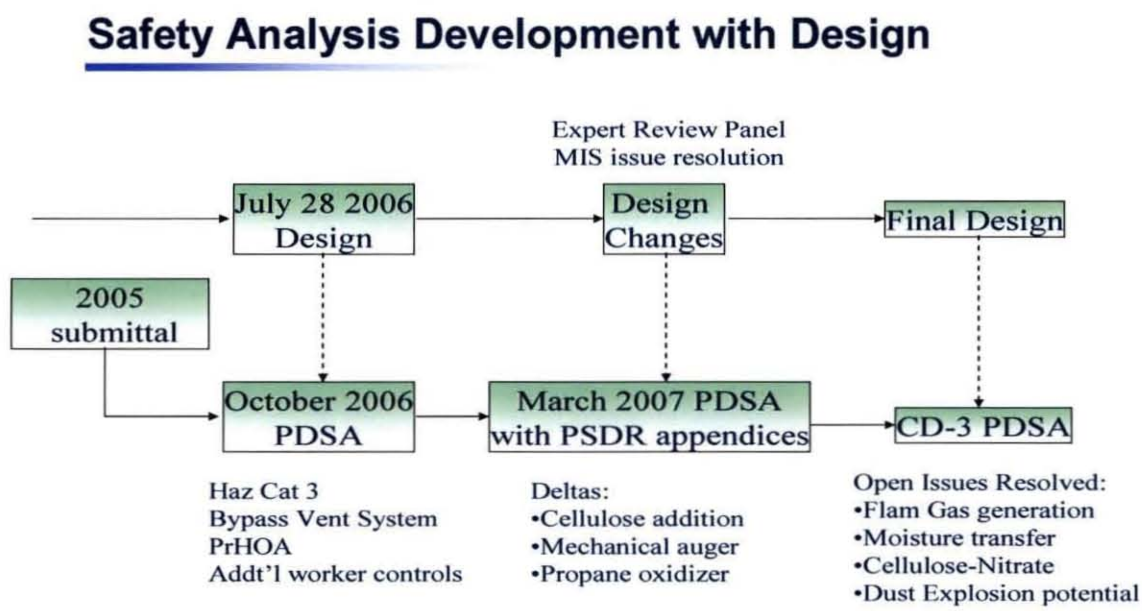


Figure 5. Design and Safety Analysis Development.

On June 19, 2007, ORP issued a Preliminary Safety Validation Report for Revision 1-A of the PDSA/PSDR with eight conditions of approval.

1. The Tank Farm Contractor (TFC) shall prepare and submit to ORP a PDSA incorporating results of the hazards analyses, accident analyses, safety system design information, and safety control strategies of final design in support of CD-3.

2. The TFC is directed to assign the same safety function to the hydraulic piping and hoses for the Waste Dryer Hydraulic Power Module that present a similar hydraulic spray fire hazard as the mechanical joints in the hydraulic system. The safety function is to protect safety-significant primary confinement and the waste dryer skid (ISO container) structural supports against the effects of a hydraulic spray fire, thus decreasing the frequency of radioactive and hazardous material releases by limiting the damage caused by the fire.

3. In the next revision of the Preliminary Fire Hazards Analysis, the TFC shall consider how the following fire parameters/phenomena affect the structural supports of the Melt Area Enclosure and OGTS, safety-significant primary confinement (both dry waste and gaseous effluent) and the achievement of safe shutdown:

   - Flashover
   - Flame Impingement
   - Temperature
   - Duration
   - Propagation
   - Soot
   - Type, amount, and location of combustible.

   In the event that SACs are deemed adequate, in lieu of engineered safety fire detection and suppression systems, the SAC shall be quantifiable and include a basis for implementation as required by DOE-STD-1186-2004. The resulting new controls, or the basis for implementation of SAC, shall be provided in the next revision of the PDSA.

4. The safety basis control strategy for the use of propane to fire the Thermal Oxidation System Burner shall be modified to identify robust safety related independent layers of protection intended to either reduce the frequency or consequence of the identified hazardous conditions associated with the use of propane within the operations area of the facility by addressing the following potential hazardous conditions:

   - Unconfined vapor explosions
   - Fire
   - Jet flame
   - Fireball.

5. The Thermal Oxidation System Burner shall be designed to meet all applicable requirements of NFPA 85, *Boiler and Combustion Systems Hazards Code*[21]. All safety systems shall be designed to meet the appropriate safety classifications. The TFC, in the next revision of the PDSA, shall identify robust safety related controls, using a systematic process, to either reduce the frequency or consequence associated with the use of propane in the DBVS facility by addressing unconfined vapor explosions, fire, jet flames, and fireballs resulting from the use of propane.

6. Defense-in-Depth controls and features shall be revised as required by DOE O 420.1A in the PDSA for submittal in support of CD-3.

7. The PDSA prepared for CD-3 shall incorporate the requirements of NFPA 69, *Explosion Prevention Systems*[22], as applicable, as the safety basis control strategy for flammable gas hazards.

8. The revision of the As Low As Reasonably Achievable (ALARA) analysis prepared for the PDSA prior to CD-3 shall provide detailed technical bases for all aspects of the shielding strategy planned for the facility. The PDSA shall contain an adequate summary of these technical bases.

Revision 2 of the Preliminary Documented Safety Analysis

For the remainder of 2007, the project design continued with hazards analyses on changes deriving from enhancements and resolutions of outstanding issues. Also, ORP and CH2M HILL agreed upon testing scope and methodologies in the areas of flammable gas generation, exothermic reactions, and dust combustibility for the cellulose addition to the glass-former mixture. External reviews of the design and safety analysis continued, but no additional significant changes resulted. ORP and CH2M HILL discussed and agreed upon the path-forward for closure of the conditions of approval.

Design for the project was completed in March 2008, and results of all the testing have been received. Revision 2 of the PDSA is scheduled for submittal to ORP in May, 2008, as part of the CD-3 package for the project. Funding levels for the project have been decreased in recent years, and funding for fiscal year 2009 has been cut, awaiting a decision by DOE on the best choice of technology to be applied to supplemental treatment of the Hanford Site waste (i.e., DBVS or an additional LAW melter at the Waste Treatment Plant). Because of this, the PDSA will be reviewed by ORP upon receipt, but an approval is not anticipated until the decision on the technology has been made and funding to the project has been re-established.

Table 2 shows the draft controls for each of the analyzed accidents in Revision 2 of the PDSA.

Table 2. Summary of Safety Structures, Systems, and Components and Technical Safety Requirements for Representative Accidents. (5 sheets)

No.	Representative accident	Safety structures, systems, and components	Technical safety requirements[a]
1.	Fires and explosions	SS: Waste dryer ISO freight container water mist system SS: Waste dryer hydraulic power module water mist system SS: Waste dryer hydraulic power module hydraulic piping, hoses, and spray shields SS: Diesel generator fuel tank and fuel line curbing SS: Propane supply system piping SS: Propane supply system stop-check valve SS: Propane monitoring system SS: Propane supply system shutoff valve SS: Flame loss interlock SS: Vehicle barriers	LCO: Waste Dryer ISO Freight Container and Hydraulic Power Module Water Mist Systems LCO: Propane Monitoring System LCO: Flame Loss Interlock SAC: ICV Container Transporter Restrictions SAC: Fire Protection Program SAC: Cellulose Limit SAC: Vehicle Barrier Controls SAC: Hoisting and Rigging Program Design Features • Location of the waste dryer steam supply skid and fuel storage tank • Location of the propane storage tank • Topography of the propane storage tank site and/or barriers
2.	Flammable gas accidents	SS: Waste staging tanks SS: Waste dryer SS: Transfer leak detection systems SS: ICV container inlet air low-flow/low-vacuum interlock[d] SS: Waste dryer vent flow path valves[b]	LCO: Transfer Leak Detection Systems LCO: ICV Container Inlet Air Low-Flow/Low-Vacuum Interlock[d] SAC: Waste Dryer Controls • Flammable gas SAC: Industrial Safety Program
3.	Waste transfer leaks	SS: Waste staging tanks SS: Waste transfer primary piping systems SS: Waste staging tank valve manifold boxes SS: Waste receipt pump skid (ISO container) SS: Hose-in-hose transfer line systems SS: Waste dryer SS: Waste dryer skid (ISO container)	LCO: Transfer Leak Detection Systems LCO: Backflow Preventers LCO: Waste Staging Tank High Level LCO: Waste Dryer Load Cell High Weight SAC: Waste Receipt Pump Skid (ISO Container) Controls • Waste receipt pump skid doors* SAC: Waste Dryer Controls • Waste dryer "openings" and seals* • Waste dryer sintered metal filter

Table 2. Summary of Safety Structures, Systems, and Components and Technical Safety Requirements for Representative Accidents. (5 sheets)

No.	Representative accident	Safety structures, systems, and components	Technical safety requirements[a]
		SS: Transfer leak detection systems SS: Backflow preventers SS: Isolation valves for double valve isolation SS: Waste staging tank high level interlocks and alarms SS: Waste dryer load cell high weight alarm SS: Waste dryer sintered metal filter SS: Vehicle barriers SS: Waste sample bottle SS: Drum filling station SS: 1st Stage Sintered Metal Filter Housing SS: Inlet and Outlet valves to 1st Stage Sintered Metal Filter SS: 2nd Stage Sintered Metal Filter Housing SS: Inlet and Outlet valves to 2nd Stage Sintered Metal Filter	SAC: Waste Dryer Skid (ISO Container) Controls • Waste dryer skid doors* SAC: Transfer Controls • Independent verification of double valve isolation • Waste staging tank valve manifold box covers* • Material balance SAC: Administrative Lock Controls SAC: Vehicle Barrier Controls SAC: Hoisting and Rigging Program SAC: Emergency Preparedness Program SAC: Drum Filling Station Controls • Drum Filling Station Doors SAC: Sintered Metal Filter Flushing Controls • Volume limit on flush water • Inlet and outlet valve controls
4.	Aboveground tank failures	SS: Waste staging tanks SS: Waste dryer SS: Vehicle barriers	SAC: Waste Staging Tank Controls • Waste staging tank pressure/vacuum relief valves* SAC: Waste Dryer Controls • Waste dryer "openings" and seals* SAC: Vehicle Barrier Controls SAC: Hoisting and Rigging Program SAC: Freeze Protection Controls*

Table 2. Summary of Safety Structures, Systems, and Components and Technical Safety Requirements for Representative Accidents. (5 sheets)

No.	Representative accident	Safety structures, systems, and components	Technical safety requirements[a]
5.	Dried waste releases	SS: Waste dryer SS: Transfer leak detection system in the waste dryer skid (ISO container) SS: DWTS primary confinement structures[c] SS: MAEB ventilation system HEPA filters SS: ICV containers SS: ICV container inlet air low-flow/low-vacuum interlock[d] SS: DWTS feed isolation valves SS: ICV container lid high temperature alarm SS: OGTS confinement structures[e] SS: Off-gas exhaust stack SS: Vehicle barriers SS: ICV container guide rails	LCO: Transfer Leak Detection Systems LCO: MAEB Ventilation System HEPA Filters LCO: ICV Container Inlet Air Low-Flow/Low-Vacuum Interlock LCO: ICV Container Lid High Temperature SAC: Waste Dryer Controls • Waste dryer "openings" and seals* SAC: ICV Container Controls • DWTS chute connections to the ICV container SAC: Vehicle Barrier Controls SAC: Hoisting and Rigging Program
6.	Toxic off-gas releases	SS: ICV containers SS: ICV container lid high temperature alarm SS: DWTS and top-off soil chutes[f] SS: OGTS confinement structures[e] SS: Off-gas quencher high temperature interlock SS: Off-gas quencher emergency water supply system SS: Propane supply system shutoff valve SS: Off-gas exhaust stack SS: OGTS bypass system[g] SS: ICV container inlet air low-flow/low-vacuum interlock[e] SS: OGTS bypass system inlet isolation valves	LCO: ICV Container Lid High Temperature LCO: Off-Gas Quencher High Temperature Interlock LCO: Off-Gas Quencher Emergency Water Supply System LCO: OGTS Bypass System LCO: ICV Container Inlet Air Low-Flow/Low-Vacuum Interlock LCO: Waste Dryer Feed/Discharge Interlock SAC: Waste Dryer Controls • Dried waste moisture limit • Isolation of filtered water to the waste dryer SAC: ICV Container Controls • DWTS and top-off soil chute connections and the OGTS connection to the ICV container SAC: Vehicle Barrier Controls SAC: Hoisting and Rigging Program

Table 2. Summary of Safety Structures, Systems, and Components and Technical Safety Requirements for Representative Accidents. (5 sheets)

No.	Representative accident	Safety structures, systems, and components	Technical safety requirements[a]
		SS: ICV container off-gas outlet isolation valves SS: DWTS feed isolation valves SS: Lower top-off soil air lock valves SS: OGTS air inlet valves[i] SS: Waste dryer feed/discharge interlock SS: Vehicle barriers	
7	Organic-nitrate reaction	SS: Waste dryer high temperature alarm SS: Dried waste feed hopper high temperature alarm	LCO: Waste Dryer High Temperature LCO: Dried Waste Feed Hopper High Temperature SAC: Cellulose Limit
8.	Process chemical releases	None required	None required
9.	Other releases	None required	None required
10.	External events[i]	None required	SAC: Emergency Preparedness Program
11.	Natural events[i]	None required	SAC: Emergency Preparedness Program

Notes:

[a]In addition to the TSRs listed for each representative accident, SAC: Source Term Controls protects the source term assumptions in RPP-CALC-30596 used in the accident analysis, and SAC: Instrumentation Controls controls instrumentation used to verify parameters to comply with the TSRs. The TSRs also establish the minimum operations shift complement necessary to respond to safety-significant system alarms.

[b]The safety-significant waste dryer vent flow path valves include the waste dryer inlet and outlet valves to vent the waste dryer through the vacuum blower to the OGTS or the OGTS bypass system.

[c]The safety-significant DWTS primary confinement structures include the structures (e.g., piping, valves, dried waste feed hopper, dried waste vertical and horizontal augers, waste feed chutes, waste feed port assemblies) that provide the confinement of waste during its transfer from the waste dryer to the ICV container.

[d]The safety-significant ICV container inlet air low-flow/low-vacuum interlock includes the ICV container inlet air low-flow and low-vacuum instrumentation, and the interlocks to open the OGTS bypass system inlet isolation valves (2) and to close the ICV container inlet and off-gas outlet isolation valves (2), the DWTS feed isolation valves (2), the lower top-off soil air lock valves (4), the OGTS air inlet valves (5), and the propane supply system shutoff valve.

[e]The safety-significant OGTS confinement structures include the piping, valves, and OGTS component housings (e.g., sintered metal filters, thermal oxidizer, quencher/scrubber, HEPA and HEGA filters, and exhaust fans) that provide confinement of toxic off-gas (NOx) and dried waste particulates from the ICV container to the off-gas exhaust stack.

[f]The safety-significant DWTS and top-off soil chutes include the structures (e.g., piping, valves) from the ICV container to and including the DWTS feed isolation valves and the lower top-off soil air lock valves.

Table 2. Summary of Safety Structures, Systems, and Components and Technical Safety Requirements for Representative Accidents. (5 sheets)

No.	Representative accident	Safety structures, systems, and components	Technical safety requirements[a]

[g]The safety-significant OGTS bypass system includes the confinement structures (e.g., piping; valves; knock-out pot, HEPA filter, and fan housings) that provide confinement of toxic off-gas (NOx) and dried waste particulates from the connection to the ICV container to the off-gas exhaust stack; the components/systems (e.g., fans, UPS, ATS, backup generator) required to maintain a vacuum in the ICV container for postulated scenarios that result is loss of OGTS flow to the ICV container; the knock-out pot that protect the HEPA filters from plugging, and the main OGTS inlet bleed lines.

[h]The OGTS air inlet valves include the SMF tempering air valve *(TV-014)*, the SMF dust transfer valve *(YV-012), the thermal oxidizer air inlet valve (FV-609)*, the burner ambient air supply valve *(FV-648)*, and the oxidation ambient air supply valve *(FV-661)*.

[i]For the external events and natural events representative accidents, the SAC: Emergency Preparedness Program is in addition to the safety-significant SSCs and/or TSRs listed for representative accidents where external events or natural events may be the accident initiator.

*The SAC is derived or also derived from the system evaluation of safety-significant SSCs in Section 4.4 of RPP-23429.

RPP-23429, 2005, *Demonstration Bulk Vitrification System Preliminary Documented Safety Analysis*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-CALC-30596, 2006, *Demonstration Bulk Vitrification System Accident Analysis Source Terms*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

ATS = automatic transfer switch.
DWTS = Dried Waste Transfer System.
HEGA = high-efficiency gas absorption.
HEPA = high-efficiency particulate air (filter).
ICV = In-Container Vitrification.
ISO = International Organization for Standardization.
LCO = limiting condition for operation.
MAEB = Melt Area Enclosure Building.
NOx = nitrogen oxides.
OGTS = Off-Gas Treatment System.
SAC = specific administrative control.
SMF = sintered metal filter.
SS = safety-significant.
SSC = structures, systems, and components.
TSR = technical safety requirement.
UPS = uninterruptible power supply.

Conclusion

During the past 5 years of the DBVS project, the safety analyses have presented a significant challenge with regard to applicability of requirements. In its earliest days, the project was a "fast track" effort intended to be a technology demonstration rather than a prototype for a production facility. Later, the project was viewed by internal and external regulators as one of the first "green field" projects to be built at Hanford in many years, and a chance to design and build a new facility rather than having to retrofit requirements onto an existing facility built, in some cases, several decades earlier. As a result, the project has grown through the years. Some of the areas in which early challenges were met and consensus achieved are discussed below.

One of the areas that presented an early challenge was hazard categorization. Separate hazard categorizations were initially considered for a two-phased DBVS project. The first phase of the project was to be "less than Hazard Category 3" due to a very limited MAR of approximately 1,000 gal. The second phase was to be Hazard Category 2, due to its physical connection to the tank farms. The separate phases were subsequently abandoned because of a lack of benefit (the hazards were determined to be mainly toxicological, so the same controls would be necessary for protection of the public, collocated and facility workers whether radiological MAR was present or not). The preliminary hazard categorization was determined to be Hazard Category 3 based on the inventory of the radiological constituents and fissile material within DBVS. Based on the hazard and accident analysis in the PDSA, a final hazard categorization of Hazard Category 3 applies to the DBVS facility as unmitigated hazardous conditions present the potential for significant local toxicological consequences during operation. There was some discussion with regulators on this topic because of the method used to derive the Hazard Category 3 ratios in DOE-STD-1027-92. The ratios are built around a radiological dose of 1 rem at 100 m as a significant dose. Even though the DBVS facility had an analyzed dose of approximately 7 rem at 100 m for the worst case dried waste release event, DOE-STD-1027-92 discusses the "generally conservative" nature of the airborne release fractions used to develop the threshold inventory values for its hazard categorizations, and allows for the scenario of some accidents, particularly those involving powders and liquids, to produce a higher airborne release fraction that that used to develop the threshold values, while not affecting the overall hazard categorization of the entire facility.

Another area of discussion during the course of the project was the "packaging" of the DBVS safety analysis documentation. The DBVS PDSA was initially developed as a "delta" analysis with the intent of appending it to the Tank Farms DSA. With the decision to have a separate DSA, the hazard and accident analysis were performed again for Revision 1 to derive the accidents directly from the DBVS facility. The programmatic chapters of the DBVS PDSA refer to Tank Farms DSA, but they also provide supplemental information for DBVS project as required.

In July 2006, DOE O 413.3 was revised to DOE O 413.3A which referenced DOE-STD-1189-2008 as the source of information regarding the form and content of a PSDR. Some of the DBVS design was completed to a degree beyond that required for a PSDR in DOE-STD-1189-2008 (i.e., remained unchanged from the PDSA submittal in October 2006) and other areas had been changed from the "final design" analyzed in that PDSA. ORP and CH2M HILL agreed that CH2M HILL would not completely revise the PDSA for the CD-2 submittal, but would supplement the PDSA with PSDR-level analyses on those areas of the design that had been modified subsequent to the previous design freeze date of July 2006, keeping the format of DOE-STD-3009-94.

Revision 2 of the DBVS PDSA is scheduled for submittal to ORP in May 2008 as part of the CD-3 package for the project. Analyses performed for the unique DBVS accident scenarios indicated that the offsite radiological risk evaluation guideline was not challenged (i.e., all safety SSCs remain safety significant rather than safety class) and all radiological consequences for onsite collocated and facility workers are "low." A considerable number of preventive and mitigative controls in the form of safety-significant SSCs, ACs, and design features were identified (see Table 2) to reduce the risk to the offsite public and onsite collocated workers from potential toxicological exposures and for hazardous conditions that present a significant risk to the facility workers.

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[3]DOE-STD-1189, 2008, *Integration of Safety into the Design Process*, U.S. Department of Energy, Washington, D.C.

[4]DOE-STD-1186, 2004, *Specific Administrative Controls*, U.S. Department of Energy, Washington, D.C.

[5]DOE O 413.3A, 2006, *Program and Project Management for the Acquisition of Capital Assets*, U.S. Department of Energy, Washington, D.C.

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[11]RPP-16215, *Bulk Vitrification Project Preliminary Engineering Report* (contact DMJMH+N, Inc. [DMJM Technology], Richland, Washington for a copy of this document).

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[15]RPP-PLAN-26909, 2007, *Supplemental Treatment Test and Demonstration Facility Process Hazard and Operation Analysis Plan*, Rev. 3, CH2M HILL Hanford Group, Inc., Richland, Washington.

[16]29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals," *Code of Federal Regulations*, as amended.

[17]40 CFR 68, "Risk Management Plans," *Code of Federal Regulations*, as amended.

[18]40 CFR 355, "Emergency Planning and Notification," *Code of Federal Regulations*, as amended.

[19]40 CFR 302, "Designation, Reportable Quantities, and Notification," *Code of Federal Regulations*, as amended.

[20]DOE-STD-1027-92, 1997, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*, Change Notice No. 1, U.S. Department of Energy, Washington, D.C.

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